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**Optics and photonics — General  
optical test methods — Measurement  
of relative irradiance in the image field**

*Optique et photonique — Méthodes générales d'essai optique —  
Méthode de mesure de l'éclairement énergétique relatif dans le  
champ image*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This second edition cancels and replaces the first edition (ISO 13653:1996), which has been technically revised.

The main changes compared to the previous edition are as follows:

- A second option for measurement, which does not require a rotation of the specimen but allows to measure along an image diameter, has been included in 7.2.3.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

In every image projected by an optical or electro-optical system, the irradiance varies from the centre to the edge independently of the object structures. It generally decreases, i.e. even an object surface of uniform radiance will be imaged with an irradiance which decreases from the image centre to the edge. In special cases, it can, however, increase. In optical systems which are rotationally invariant, the variation will not always be rotationally invariant, for example if limiting apertures are not rotationally invariant.

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# Optics and photonics — General optical test methods — Measurement of relative irradiance in the image field

## 1 Scope

This document specifies general optical test methods for the measurement of the relative irradiance in the image field.

This document is applicable to optical imaging systems in the optical spectral region from  $\lambda = 100$  nm to  $\lambda = 1$   $\mu$ m. Theoretical reflections and the comparison with the calculation apply only to optical systems. This document is applicable to rotationally invariant and rotationally variant systems; anamorphic systems, for example, are included.

Telescopic systems are also included. The title of this document refers to the relative irradiance in the image field, but this document is also applicable to determination of the relative radiant power.

NOTE For telescopic systems, it is suitable to state only the radiant power; for most imaging systems, the conversion from radiant power to irradiance is easy.

As far as measurements are concerned, this document is also applicable to electro-optical systems.

The two methods described differ particularly in the influence of veiling glare.

## 2 Normative references

There are no normative references in this document.  
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## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1

#### relative irradiance

quotient of radiant power and surface area

Note 1 to entry: When a surface element of the object is imaged, the irradiance in the image is a function

- of the object-space pupil field angle  $\omega_p$ ;
- of the radiant power which originates from the object element and passes through the lens (and possibly - also through the electro-optical imaging element);
- of the size of the image surface element which is struck by the radiant power.

Note 2 to entry: Radiant power and surface area are functions of the object-space pupil field angle  $\omega_p$  or of the image position  $(u', v')$ .

Note 3 to entry: The relative irradiance is related to the axial surface element.

**3.2  
object-space pupil field angle**

$\omega_p$   
angle formed by the optical axis and the line joining the centre of the entrance pupil and the object point

**3.3  
image-space pupil field angle**

$\omega'_p$   
angle formed by the optical axis and the line joining the centre of the exit pupil and the image point

**4 Quantities, symbols and units**

See [Table 1](#).

**Table 1 — Quantities, symbols and units**

Quantity	Symbol	Unit
Relative irradiance	$E_{rel}(\omega_p)$	%
Function for natural fall-off in brightness	$F_{nat}(\omega_p)$	
Function for relative pupil surface	$F_p(\omega_p)$	
Function for vignetting	$F_{vig}(\omega_p)$	
Function for relative transmission	$F_T(\omega_p)$	
Influence function of distortion	$F_{ver}(\omega_p)$	
Relative distortion	$V_r$	%
Image coordinates	$u$	mm
	$v'$	mm
Object height (one dimensional)	$h$	mm
Image height (one dimensional)	$h'$	mm
Pupil field angle, object-space	$\omega_p$	rad, degree
Pupil field angle, image-space	$\omega'_p$	rad, degree
Azimuth of object to be measured	$\Phi$	rad, degree
Wall thickness of the analysing aperture	$t$	mm
Diameter of the analysing aperture	$d$	mm

**5 Designation**

Two measurement procedures are specified, the first of which has two variants. They are distinguished by symbols. See [Table 2](#).

**Table 2 — Symbols for the measurement procedures**

Symbol	Measurement procedure
A1	measurement of the relative irradiance at finite image distance
A2	measurement of the relative irradiance at infinite image distance
B	measurement of the relative radiant power

EXAMPLE Designation of a measurement of relative irradiance according to measurement procedure A1:

**Measurement of relative irradiance ISO 13653 – A1**



## 6 Description of measurement procedures

### 6.1 Factors influencing the relative irradiance

#### 6.1.1 General

The angular dependence of the relative irradiance is due to several factors which are independent of one another. In the various measurement and calculation procedures, they are allowed in different ways. It is therefore important to know the individual influence factors. The provisions of 6.1.2 to 6.1.7 are based on the assumption that the object surface is radiant Lambertian and the optical system has a flat entrance pupil.

#### 6.1.2 Natural fall-off in brightness, $F_{\text{nat}} = \cos^4 \omega_p$ (cos<sup>4</sup> law)

This cos<sup>4</sup> law shall always apply if the pupil boundary is flat and perpendicular to the axis, the aperture of the test specimen small and the detector area a plane perpendicular to the axis.

#### 6.1.3 Relative pupil surface, $F_p(\omega_p)$

Due to pupil aberrations, the surface of the entrance pupil as an image formed by the aperture stop is a function of the pupil field angle if lens elements are arranged between the object and the aperture stop. The relative surface shall be related to the pupil surface for  $\omega_p = 0$ .

#### 6.1.4 Vignetting, $F_{\text{vig}}(\omega_p)$

With increasing pupil field angle (rims in front of and behind the aperture stop and other stops can limit (vignette) the aperture.

#### 6.1.5 Influence of the transmission, $F_T(\omega_p)$

Any change of the incident angle on the surfaces of the optical components (lenses, prisms) can result in a change of the reflectivity. The net transmission can change because the paths in glass are a function of the pupil field angle.

#### 6.1.6 Change in size of the image surface element due to distortion

At the image scale  $\beta' = 0$

$$F_{\text{ver}}(\omega_p) = \frac{1}{\left(1 + \frac{V_r}{100}\right) \cdot \left(1 + \frac{V_r}{100} + \frac{\sin \omega_p \cdot \cos \omega_p}{100} \cdot \frac{dV_r}{d\omega_p}\right)}$$

at finite image scale:

$$F_{\text{ver}}(h) = \frac{1}{\left(1 + \frac{V_r}{100}\right) \cdot \left(1 + \frac{V_r}{100} + \frac{h}{100} \cdot \frac{dV_r}{dh}\right)}$$

### 6.1.7 Resulting relative irradiance

For the resulting relative irradiance in the image field as a function of the pupil field angle, the following formula is valid:

$$E_{\text{rel}}(\omega_p) = \cos^4 \omega_p \cdot F_p(\omega_p) \cdot F_{\text{vig}}(\omega_p) \cdot F_T(\omega_p) \cdot F_{\text{ver}}(\omega_p)$$

The first four factors are related to a change in radiant power, whereas the last value characterizes the variation in size of the image surface element.

When making irradiance measurements, the radiant power shall pass through the optical system in the same direction that is experienced in normal operation because the influence of distortion and veiling glare will change when the direction of beam travel is reversed.

## 6.2 Classification of the measurement procedures

Two different measurement procedures are generally acceptable: irradiance measurement and radiant power measurement.

In the case of imaging systems, the procedure for irradiance measurements directly takes all five factors in the formula in 6.1.7 into account, and shall, therefore, be given preference.

The procedure of radiant power measurement neglects the effect of distortion on the size of the image surface element. If the value is known, it can be taken into account by calculation.

NOTE For higher accuracy measurements it can be necessary to account for the distortion by calculation. For lower accuracy measurements, it can be neglected. For example at  $\omega = 25^\circ$ ,  $V_r = 1\%$ , quadratic dependence:  $F_{\text{ver}} = 0,961$ .

The result of the measurement shall be multiplied by the factor  $\cos^3 \omega_p$  so that the relative irradiance is obtained from the relative radiant power.

As compared with the method of irradiance measurement, this procedure offers the advantage that the result is generally influenced to a lesser extent by veiling glare.

According to this document, telescopic systems shall be measured solely by the method of radiant power measurement.

## 6.3 Brief description of the irradiance measurement

The relative irradiance shall be determined as a function of the image height. This measurement presupposes that there is a uniformly radiating surface in the object space, which behaves as a Lambertian emitter and as a uniform radiance. It need not, however, be situated in the object surface but can also be arranged directly in front of the entrance pupil.

A small reference surface with photoelectric detector shall be displaced by a measurable amount in the image plane; the irradiance shall be measured in arbitrary units as a function of the image height  $h'$ , and the measured value shall be related to the axial value (procedure A1, see [Figure 1](#)).

In systems with an infinitely great image distance (e.g. projection lenses), the diaphragm can be arranged at the focus of an auxiliary optical system (telescope optics) which is turned to a measurable degree about the exit pupil of the object (procedure A2, see [Figure 2](#)). The irradiance rated by the radiation detector shall be determined according to the  $\cos^4$  law.

## 6.4 Brief description of the radiant power measurement

To measure the relative radiant power, the test specimen shall be irradiated with a collimated bundle of rays. The axes of collimator and test specimen can be swung in relation to one another.

In the image space, the passing radiant power shall be measured relative to the axial value as a function of the object-space pupil field angle  $\omega_p$ , using an integrating sphere and a photoelectric detector (procedure B, see [Figure 3](#)).

## 7 Measurement of relative irradiance

### 7.1 Description of the measuring set-up

#### 7.1.1 Source of radiation

To represent a Lambertian radiation characteristic, it is advantageous to insert a diffusing screen into the aperture of an integrating sphere according to [Figure 1](#). In the spectral region in which the specimen is used, the inside surface of the integrating sphere shall be non-selective, and the diffusing screen shall ensure uniform radiance over that part of its surface which is made use of.

The source of radiation shall emit radiation into the test specimen at least from the useful range of the pupil field angle. Within this range, the constancy of the radiance shall be better than 2 %.

#### 7.1.2 Test specimen holder

The test specimen shall be held so that the front edge of its mount abuts almost directly on the diffusing screen or extends so far to the aperture of the integrating sphere that irradiation from the entire useful range of the pupil field angle is ensured.

The test specimen holder may be of the rigid type. To measure in different azimuths test specimens whose mechanical design is not rotationally invariant shall, however, be rotatable about their own axes.

#### 7.1.3 Measuring system

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##### 7.1.3.1 General

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The measuring system shall consist of the diaphragm, a filter frame and a radiation detector. It shall be possible to axially displace the measuring system so that it can be adjusted to the respective image plane. To adjust the image point, the system shall be displaceable in the image plane by a measurable amount. An auxiliary device is necessary for focussing.

To measure test specimens with an infinitely great image distance, the measuring system shall be arranged in the axial image point of an auxiliary optical system (telescope lens). It shall be possible to horizontally swing the auxiliary optical system, together with the measuring system, to a measurable degree about the exit pupil of the test specimen.

##### 7.1.3.2 Analysing aperture

The analysing aperture has an opening whose size should not exceed 2 % of the maximum image height  $h'$ . If this value is exceeded, this is to be stated. The material thickness at its edge and the cone angle at which the opening is chamfered shall be selected so that diaphragm vignetting is less than 1 % even at the greatest image-space pupil field angle  $\omega'_p$  occurring.

The following formula shall apply to circular diaphragms:

$$t \cdot \tan \omega'_p < 0,01 d$$

where

$t$  is the wall thickness of the diaphragm;

$d$  is the diameter of the diaphragm.